VIL DENSITY AS A HAIL INDICATOR

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VIL (Vertically Integrated Liquid) is a function of reflectivity, and converts reflectivity data into an equivalent liquid water content value based on drop-size distribution and a reflectivity factor. This factor is proportional to the total number of targets within a measured volume and to the target diameters taken to the sixth power. Thus, target diameter has a much greater effect on reflectivity than does the number of targets. Reflectivity increases exponentially as target diameter increases. Thus, VIL increases exponentially with reflectivity, so high VIL values require high reflectivity values, usually implying the presence of large targets (hail) aloft. As a result, VIL is used to identify thunderstorms that likely contain large hail and/or a deep layer of large drop sizes.

However, there are several potential problems with using VIL by itself:

1) VIL is air mass dependent, e.g., convection in colder air masses may produce severe hail with relatively low VILs, while those in warmer air masses may not produce severe hail with high VILs.

2) Problem 1) requires determination of a VIL-of-the-day (i.e., a threshold VIL value that is associated with hail of 3/4 inch diameter or larger on a particular day; this value will change from day to day [and even on the same day] and from location to location depending on atmospheric temperature, moisture, and wind shear profiles). However, this can cause a second problem. The VIL-of-the-day assumes all thunderstorms within the radar umbrella will have similar characteristics, i.e., a valid threshold VIL for one storm will be the same for all other storms. This assumption is not necessarily true, especially as convective interactions disrupt the larger-scale environment from which the threshold VIL value was calculated.

3) VIL is an integration of reflectivity throughout the height/depth of a particular storm. This generally results in low VILs for short storms, and high VILs for tall storms. Thus, VIL alone may not be sufficient to distinguish tall storms with low overall reflectivity (smaller targets, including possible small hail) from short storms with high reflectivity (larger targets, including possible large hail).

4) Actual storm VIL values must be reasonably accurate to compare to a pre-determined threshold VIL value. Values of and short-term trends in VIL may not always be accurate, especially for storms very close to and very distant from the radar, and/or in VCP 21 where less sampling (and thus more vertical averaging) may be occurring higher up in the storm.

To eliminate some of the inherent problems with using VIL alone, the use of "VIL Density" as a severe hail indicator was studied at the weather office in Tulsa, OK in 1994 and 1995. Their study included 221 thunderstorms, the majority of which produced severe hail.

VIL Density = VIL ÷ Echo Top (units are g/m^3 when multiplied by 1000)

VIL Density is a parameter that "normalizes" the VIL using the height/depth (echo top) of a thunderstorm, i.e., a cell's VIL is compared to the cell's echo top, which basically eliminates the air mass dependency of VIL alone and the problematic assumptions of VIL-of-the-day. Therefore, VIL Density can be used to identify thunderstorms with high reflectivities *relative to their height.* Unlike VIL which usually increases as storms increase in height, VIL Density increases primarily due to increases in target size. Thus, as VIL Density increases, hail cores tend to be deeper, more intense, and reported hail sizes tend to be larger. Thunderstorms with larger VIL Density values generally produce larger hailstones at the surface.

VIL Density Results:

SEVERE THUNDERSTORM / HAIL THRESHOLDS

VIL Density > 3.28	<<	Identified 97% of severe hail cases, but gave a 25% false alarm rate.
VIL Density > 3.50	<<	Identified 91%of severe hail cases, with only a 5.5% false alarm rate.
VIL Density = 3.0-3.5	<<	Small hail and marginal SVR Hail
VIL Density = 3.5-3.9	<<	Mostly SVR Hail
VIL Density > 4.0	<<	SVR Hail

HAIL SIZE VERSUS VIL DENSITY THRESHOLDS

VIL Density < 3.0	<<	Mostly non-severe/small hail but a few dime to nickel size severe cases.
VIL Density = 3.0-3.4	<<	About half the cases non-severe hail, and half of cases severe with dime to nickel size.
VIL Density = 3.5-3.9	<<	Nearly all severe cases, with most dime to nickel size, with a couple one inch size.
VIL Density = 4.0-4.4	<<	All severe hail cases, with most dime to nickel size but several an inch or more and a few golfball size.
VIL Density = 4.5-4.9	<<	All severe hail cases, with half of cases dime to nickel size and half of cases an inch in diameter or more, including several golfball size or larger.
VIL Density > 4.9	<<	All severe hail cases, with most over an inch in diameter and a number of events larger than golfball size.

Hail Size > 1 inch	<<	VIL Density > 4.0 in 91% of the cases.
Hail Size > Golfball	<<	VIL Density > 4.3 in 88% of the cases.

VIL Density limitations/considerations:

1) The method for calculating VIL can affect VIL Density values, depending on cell movement, tilt, and range. VIL/VIL Density values should be quite accurate for slow moving, vertical storms. However, VIL values may not be accurate for fast moving storms or for slow moving, strongly tilted storms. In these cases, VIL values may be averaged resulting in a lower VIL Density. **In this study, most of the low VIL Density storms that produced severe hail occurred in fast moving bow echo events, where storm motion and tilt were maximized. Thus, threshold VIL Density values for fast moving/strongly tilted storms may be about > 3.3. For slow moving, vertical storms, threshold VIL Density values may be about >3.8-4.0.** For distant storms, VIL and VIL Density may be overestimated.

2) WSR-88D echo tops (reflectivity values >18 dBZ) may not be accurate due to discrete elevation scan strategies and product resolution. Echo tops may vary with changes in range, despite no actual change in thunderstorm top. This is especially true in VCP 21 and for storms close to the radar, where less sampling of higher altitudes in the storm will occur, resulting in a truncation of echo top height. However, VIL Density is not affected that much by this truncation, since the reflectivity/VIL of the storm is normalized by its height. **In general, VCP 11 does a better job in estimating both VIL values and echo tops than VCP 21. In this study, VCP 21 was used primarily** (due to its better velocity measurements than VCP 11).

3) Verification, as always, has some inherent problems. Only verified large hail reports were used in the study, along with non-severe hail cases that passed over a populated area. However, actual maximum hail size associated with some thunderstorms in this study may not have been recorded, due to a lack of follow-up phone calls after the initial severe hail verification.

4) **VIL Density only indicates hail aloft. This can cause inconsistencies between VIL Density values and ground truth. This problem may occur in cases of quite high freezing levels (deep warm cloud and subcloud layer) or if the hail encounters significant liquid water when falling, in which case melting may be substantial reducing the observed hail size at the ground.**

Procedure to use VIL Density graph operationally:

The VIL Density graph below reveals VIL values versus echo top (in kft). To use the chart, determine from the same volume scan on the WSR-88D a storm's VIL value and echo top (>18 dBZ) using either the echo tops product or a vertical cross section. (Remember that the echo tops product may only give coarse top values, especially if using VCP 21 and for storms close to the radar). After obtaining this information, employ the chart to find your point of intersection and compare it to the VIL Density lines. If your point is to the right of the appropriate critical VIL Density line, then consider issuing a severe thunderstorm warning. A value to the right of the 3.5 line has a Moderate potential for severe hail. A value to the right of the 4.0 line has a High potential. However, remember that this method has limitations and certainly is not fool-proof. For example, it is possible that a storm may (may not) produce large hail even with a VIL Density value below (above) a threshold. Also, be aware of the VIL Density limitations cited above. Use this method as an additional tool for assessing hail potential. Always consider the overall storm structure and evolution before issuing a warning.